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SEMICONDUCTOR LASER BASED ON MATRIX, ARRAY OR SINGLE TRIANGLE OPTICAL CAVITY WITH SPATIALLY DISTRIBUTED CURRENT INJECTION

BACKGROUND OF THE INVENTION

1. FIELD OF THE INVENTION

The invention relates to light output devices and, more particularly, to triangle optical cavities with spatially distributed current injection for light generation and output.

2. DESCRIPTION OF THE RELATED ART

Light output devices such as semiconductor laser diodes having optical cavities for light generation are commonly known and have been implemented in numerous applications in the art. However, in prior art semiconductor laser diodes, light generation in the optical cavity leads to drawbacks such as the uncontrolled generation of a large number of optical modes. There is therefore a general need in the art for a light output device

that overcomes the aforementioned drawbacks in the prior art, i.e., the uncontrolled generation of optical modes, and more particularly, a laser diode with an optical cavity that can operate in a single optical mode or controllable multiple modes.

SUMMARY OF THE INVENTION

The invention provides a method and device for light generation wherein an embodiment of the device comprises a lower electrode, a substrate formed on the lower electrode, a triangle mesa structure formed on the substrate for lateral confinement of light, a triangle optical cavity formed in the mesa structure, an upper electrode formed on the mesa structure, and a plurality of contact spots formed on the upper electrode that correspond to the maxima of optical field intensity for at least one optical mode on a lateral plane in the triangle optical cavity. A particular embodiment of the method according to the invention comprises the steps of forming a substrate on a lower electrode, forming a triangle mesa structure on the substrate for lateral confinement of light, forming a triangle optical cavity in the mesa structure, forming an upper electrode on the mesa structure, forming a plurality of contact spots on the upper electrode corresponding to the maxima of optical field intensity for at least one optical mode on a lateral plane in the triangle optical cavity, and propagating light or laser through the mesa structure.

An additional embodiment of the light output device according to the invention comprises a lower electrode, a substrate formed on the lower electrode, a plurality of triangle mesa structures formed on the substrate for lateral confinement of light, a triangle optical cavity formed in each of the mesa structures, an upper electrode formed on each of the triangle mesa structures, a light output structure formed on the substrate for directing and controlling the light output from the device, and contact spots formed on the upper electrodes that correspond to the maxima of optical

field intensity for at least one optical mode on a lateral plane in the triangle optical cavities.

With the method and device for light generation according to the invention, drawbacks in the prior art, i.e., the uncontrolled generation of optical modes, are advantageously overcome, and more particularly, light generation with a triangle optical cavity can advantageously be implemented in a single optical mode or controllable multiple modes.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other advantages and features of the invention will become more apparent from the detailed description of the preferred embodiments of the invention given below with reference to the accompanying drawings, not necessarily drawn to scale, in which:

Fig. **1** is a diagram generally illustrating an embodiment of the light output device having a triangle optical cavity according to the invention;

Fig. **2** is a diagram illustrating a further embodiment of the light output device having a truncated triangle mesa structure according to the invention;

Fig. **3** is a diagram illustrating an additional embodiment of the light output device having an array of optical cavities and triangle mesa structures according to the invention;

Fig. **4** is a diagram illustrating another embodiment of the light output device having a matrix of optical cavities and triangle mesa structures according to the invention;

Fig. **5** is a diagram illustrating yet another embodiment of the light output device having a hollow matrix of optical cavities and triangle mesa structures according to the invention;

Fig. **6** is a perspective view of a particular embodiment of a triangle mesa structure having a triangle optical cavity according to the

invention in which a two-dimensional side view of the mesa structure is shown;

Fig. **7** is a diagram illustrating the optical field intensity distribution of the lowest optical mode in a triangle optical cavity having a single maximum of optical field intensity therein;

Fig. **8** is a two-dimensional diagram illustrating the shape of a contact spot in an upper electrode according to the invention with the lowest optical mode in a triangle optical cavity having a single maximum of optical field intensity therein;

Fig. **9** is a diagram illustrating the optical field intensity distribution of a triangle optical cavity in an embodiment of the light output device according to the invention;

Figs. **10** and **11** are two-dimensional diagrams illustrating the shapes of contact spots in an upper electrode for selected cut-off levels in an embodiment of the light output device according to the invention corresponding to Fig. **9**;

Fig. **12** is a diagram illustrating the optical field intensity distribution of a triangle optical cavity in another embodiment of the light output device according to the invention;

Figs. **13** and **14** are two-dimensional diagrams illustrating the shapes of contact spots in an upper electrode for selected cut-off levels in an embodiment of the light output device according to the invention corresponding to Fig. **12**;

Fig. **15** is a diagram illustrating the optical field intensity distribution of a triangle optical cavity in yet another embodiment of the light output device according to the invention;

Figs. **16** and **17** are two-dimensional diagrams illustrating the shapes of contact spots in an upper electrode for selected cut-off levels in an

embodiment of the light output device according to the invention corresponding to Fig. **15**;

Fig. **18** is a diagram illustrating the optical field intensity distribution of a triangle optical cavity in a further embodiment of the light output device according to the invention;

Figs. **19**, **20** and **21** are two-dimensional diagrams illustrating the shapes of contact spots in an upper electrode for selected cut-off levels in an embodiment of the light output device according to the invention corresponding to Fig. **18**;

Fig. **22** is a diagram illustrating the optical field intensity distribution of a triangle optical cavity in an additional embodiment of the light output device according to the invention;

Figs. **23** and **24** are two-dimensional diagrams illustrating the shapes of contact spots in an upper electrode for selected cut-off levels in an embodiment of the light output device according to the invention corresponding to Fig. **22**;

Fig. **25** is a diagram illustrating the optical field intensity distribution of a triangle optical cavity in a yet additional embodiment of the light output device according to the invention;

Figs. **26** and **27** are two-dimensional diagrams illustrating the shapes of contact spots in an upper electrode for selected cut-off levels in an embodiment of the light output device according to the invention corresponding to Fig. **25**;

Fig. **28** is a diagram illustrating the optical field intensity distribution of a triangle optical cavity in another embodiment of the light output device according to the invention;

Figs. **29**, **30**, **31** and **32** are two-dimensional diagrams illustrating the shapes of contact spots in an upper electrode for selected

cut-off levels in an embodiment of the light output device according to the invention corresponding to Fig. **28**;

Figs. **33**, **34**, **35** and **36** are diagrams illustrating various embodiments of the light output device having a triangle optical cavity according to the invention;

Figs. **37** and **38** are diagrams illustrating additional embodiments of the light output device having an array of optical cavities and triangle mesa structures according to the invention; and

Fig. **39** is a diagram illustrating yet another embodiment of the light output device having a matrix of optical cavities and triangle mesa structures according to the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Fig. **1** is a diagram generally illustrating an embodiment of the light output device having a triangle optical cavity according to the invention. According to this general embodiment of the invention, the light output device comprises a single-contact lower electrode **1**, a substrate **2**, a triangle mesa structure **3**, and a multi-contact upper electrode **4**. The substrate **2** is formed on the lower electrode **1**, whereas the triangle mesa structure **3** is formed on the substrate for lateral confinement of light. A triangle optical cavity is formed in the mesa structure **3**, whereas the upper electrode **4** is formed on the mesa structure. A plurality of contact spots are formed on the multi-contact upper electrode **4** that correspond to the maxima of optical field intensity for at least one optical mode on a lateral plane in the triangle optical cavity. The substrate **2** includes an active layer which can be made of a group III-V or II-VI semiconductor double heterostructure, a single quantum well (SQW), a multiple quantum well (MQW) or a current asymmetric resonance tunneling structure. As light or laser is propagated through the mesa structure **3**, drawbacks in the prior art, i.e., the

uncontrolled generation of optical modes, are advantageously overcome, and more particularly, light generation in the triangle optical cavity of the mesa structure can advantageously be implemented in a single optical mode or controllable multiple modes.

As the contact spots formed on the multi-contact upper electrode **4** correspond to the maxima of optical field intensity on a lateral plane in the triangle optical cavity in the mesa structure **3**, the number of contact spots, N_{spot}, is equal to the number of the optical field intensity maxima, N_{max}, for the chosen optical mode in the triangle optical cavity, as follows:

$$N_{spot} = N_{max} \qquad \text{Eq. (1)}$$

Fig. **6** is a perspective view of a particular embodiment of a triangle mesa structure having a triangle optical cavity according to the invention, where a two-dimensional side view of the mesa structure is shown. Referring to Figs. **1** and **6**, the mesa structure **3** having a triangle optical cavity comprises an upper mirror **61**, a waveguide layer **62** for vertical light confinement, and a lower mirror **63**. The waveguide layer for vertical light confinement can be made of group III-V or II-VI semiconductor heterostructure or double heterostructure, index-graded structure or superlattice structure. As the light or laser propagates along path **64** in the triangle optical cavity, an effective propagating angle θ_1 is formed along the angle view **65**. The optical modes in the triangle optical cavity can be characterized by the lateral quantum number n, and longitudinal quantum number m, which are both even or odd, and $n \neq m$. As θ_1 represents the effective propagating angle for semiconductor waveguide layer **62** and a is the length of the side of the triangle optical cavity in the triangle mesa structure **3**, the corresponding wavelength λ is given by the following equation:

$$\lambda = 3an_r \cos\theta_1 / \sqrt{3n^2 + m^2} \qquad \text{Eq. (2)}$$

In simple planar wave guides made of double heterostructures or index-graded structures where $\theta_1 << \pi/2$, $cos\theta_1 \approx 1$ and the size a of the triangle optical cavity for small quantum numbers n and m is generally comparable with the light wavelength λ. In complex planar wave guides having superlattice mirrors with high reflectivity $\theta_1 \approx \pi/2$, $cos\theta_1 << 1$ and the size a of the triangle cavity for small quantum numbers n and m can be made much larger than the light wavelength λ.

Fig. **2** is a diagram illustrating a further embodiment of the light output device having a truncated triangle mesa structure according to the invention. According to this particular embodiment of the invention, the light output device comprises a lower electrode **21**, a substrate **22**, a truncated triangle mesa structure **23**, and an upper multi-contact electrode **24** with a plurality of contact spots. This particular embodiment is similar in structure to the embodiment shown in Fig. **1**, except the triangle mesa structure **23** truncated at the corners **25**. Accordingly, the substrate **22** is formed on the single-contact lower electrode **21**, whereas the truncated mesa structure **23** is formed on the substrate **22** for lateral confinement of light. A triangle optical cavity is formed in the mesa structure **23**, whereas upper electrode **24** is formed on the mesa structure **23**. The contact spots are formed on the multi-contact upper electrode **24** that correspond to the maxima of optical field intensity for at least one optical mode on a lateral plane in the triangle optical cavity.

Fig. **7** is a three-dimensional diagram that illustrates the optical field intensity distribution of the lowest optical mode in a triangle optical cavity **74** having a single maximum of optical field intensity therein. Axes **71** and **72** represent the X and Y coordinates for the triangle optical cavity, respectively, and Z-axis **73** represents the optical field intensity. The dotted line **74** represents the border of the triangle optical cavity in the mesa structure. For the lowest optical mode with quantum numbers $n = 1$ and m

$=3$, there is a single maximum **75** of optical field intensity in the triangle optical cavity. In accordance with the invention, the upper electrode for the light output device accordingly includes a single contact spot, $N_{spot} = 1$, corresponding to the single maximum **75** at the apex of the triangle optical cavity, located at the center of the triangle mesa structure.

The shape of the contact spots formed on the upper electrode in the triangle mesa structure varies with the degree of optical mode selectivity determined by the cut-off level L_c of the optical field intensity for the given optical mode at a lateral plane of the triangle optical cavity. Fig. **8** is a two-dimensional diagram that illustrates the shape of a contact spot in an upper electrode according to the invention with the lowest optical mode with quantum numbers $n = 1$ and $m = 3$ at a lateral plane in a triangle optical cavity having a single maximum of optical field intensity therein. Axes **81** and **82** represent X and Y coordinates for the triangle optical cavity, respectively. The dotted line **83** represents the border of the triangle optical cavity in the mesa structure. Contours **84, 85** and **86** represent the shapes of the contact spot for the upper electrode calculated at cut-off levels $L_c = 0.1$, $L_c = 0.5$ and $L_c = 0.9$, respectively, at a lateral plane of the triangle optical cavity. With an increase in the longitudinal and lateral quantum numbers m and n, the number of maxima of optical field intensity increases as illustrated in Figs. **9, 12, 15, 18, 22** and **25**, the number of contact spots Figs. **11, 14, 17, 20** and **21**, respectively, is accordingly increased for selective excitation of the given optical mode.

Fig. **9** is a diagram that illustrates the optical field intensity distribution of a triangle optical cavity in an embodiment of the light output device according to the invention, e.g., as shown in Fig. **1**. Figs. **10** and **11** are two-dimensional diagrams that illustrate the shapes of contact spots in an upper electrode for selected cut-off levels at a lateral plane in the triangle optical cavity in an embodiment of the light output device according to the

invention corresponding to Fig. **9**. Fig. **9** shows the optical field intensity distribution of the optical mode with lateral and longitudinal quantum numbers $n=1$ and $m=5$ in the triangle optical cavity. Axes **91** and **92** represent the X and Y coordinates for the triangle optical cavity, respectively, Z-axis **93** represents the optical field intensity, and the dotted line **94** represents the border of the triangle optical cavity. There are three maxima of optical field intensity in for the optical mode having lateral and longitudinal quantum numbers $n=1$ and $m=5$, including the **95** is an intensity maximum **95**. The dotted line **96** represents the border of an area near the triangle apex with low optical field intensity that can be cut off to form a truncated triangle optical cavity in another embodiment according to the invention. Fig. **10** shows the calculated shapes of the contact spots for the upper electrode for the given optical mode in the triangle optical cavity with quantum numbers $n=1$ and $m=5$ corresponding to selected cut-off levels corresponding to a given lateral plane of the triangle optical cavity. Axes **10-1** and **10-2** represent the X and Y coordinates for the triangle optical cavity, respectively, and the dotted line **10-3** represents the border of the triangle optical cavity. Contours **10-4**, **10-5** and **10-6** represent the shapes of the contact spots formed on the upper electrode calculated at cut-off levels $L_c=0.1$, $L_c=0.5$ and $L_c=0.9$, respectively. The dotted line **10-7** represents the border of an area near the triangle apex with low optical intensity that can be cut off to form a truncated triangle optical cavity in another embodiment according to the invention. Fig. **11** shows the shapes of the triple contact spots in the upper electrode at the cut-off level $L_c=0.5$ for the given optical mode at a given lateral plane in the triangle optical cavity with quantum numbers $n=1$ and $m=5$ where axes **11-1** and **11-2** represent the X and Y coordinates for the triangle optical cavity, respectively, the dotted line **11-3** represents the border of the triangle optical

cavity, and contour **11-4** represents the shape of a given contact spot in the upper electrode.

Fig. **3** is a diagram illustrating an additional embodiment of the light output device having an array of optical cavities and triangle mesa structures according to the invention. According to this particular embodiment of the invention, the light output device comprises a lower electrode **31**, a substrate **32**, a plurality of triangle mesa structures **33** having triangle optical cavities, an upper multi-contact electrode **34** having a plurality of contact spots, a plurality of trenches **35** providing optical connection between adjacent mesa structures, and light output element **36** for outputting light in the direction **37**. This particular embodiment is similar in structure to the embodiment shown in Fig. **1**, except that the light output device includes a plurality of triangle mesa structures **33** arranged in an array on the substrate **32**, and a light output element **36** for directing the light output in the direction **37**. In this particular embodiment, the substrate **32** is a conducting n-GaAs substrate with the light output by the light output device, e.g., a semiconductor laser diode, being generated with wavelength λ in the general region of 700 nm to 1300. Furthermore, the triangle mesa structures **33** can also be truncated triangle mesa structures, and the triangle optical cavities can be truncated as well, as discussed herein and above. In a further variation of this particular embodiment, the substrate **32** can be a conducting n-InP substrate with the light output by the light output device being generated with wavelength λ in the general region of 1300 nm to 1550.

Fig. **4** is a diagram illustrating another embodiment of the light output device having a matrix of optical cavities and triangle mesa structures according to the invention. According to this particular embodiment of the invention, the light output device comprises a lower electrode **41**, a substrate **42**, a plurality of triangle mesa structures **43** having triangle optical

cavities, an upper multi-contact electrode **44** having a plurality of contact spots, a plurality of trenches **45** providing optical connection between adjacent mesa structures, and a light output element **46** for outputting light in the direction **47**. This particular embodiment is similar in structure to the embodiment shown in Fig. **1**, except that the light output device includes a plurality of triangle mesa structures **43** arranged in a matrix on the substrate **42**, and a light output structure **46** for directing the light output in the direction **47**. In this particular embodiment, the substrate **42** is a conducting n-GaAs substrate with the light output by the light output device, e.g., a semiconductor laser diode, being generated with wavelength λ in the general region of 700 nm to 1300. Moreover, the triangle mesa structures **43** can also be truncated triangle mesa structures, and the triangle optical cavities can be truncated as well, as discussed herein and above. In a further variation of this particular embodiment, the substrate **42** can be a conducting n-InP substrate with the light output by the light output device being generated with wavelength λ in the general region of 1300 nm to 1550.

Fig. **5** is a diagram illustrating yet another embodiment of the light output device having a hollow matrix of optical cavities and triangle mesa structures according to the invention. According to this particular embodiment of the invention, the light output device, in the form of a semiconductor laser gyroscope, comprises a lower electrode **51**, a substrate **52**, a plurality of triangle mesa structures **53** having triangle optical cavities, an upper multi-contact electrode **54** having a plurality of contact spots formed thereon, a plurality of trenches **55** providing optical connection between adjacent mesa structures, a hollow **56** in the center of the matrix, and a light output element **57** for outputting light in the direction **58**. This particular embodiment is similar in structure to the embodiment shown in Fig. **1**, except that the light output device includes a plurality of triangle mesa structures **53** arranged in a matrix with a hollow **56** on the substrate

52, and a light output element **56** for directing the light output in the direction **57**. In this particular embodiment, the substrate **52** is a conducting n-GaAs substrate with the light output by the light output device, e.g., a semiconductor laser diode, being generated with wavelength λ in the general region of 700 nm to 1300. Furthermore, the triangle mesa structures **53** can also be truncated triangle mesa structures, and the triangle optical cavities can be truncated as well, as discussed herein and above.

With an increase in the longitudinal and lateral quantum numbers m and n, the number of maxima of optical field intensity increases as illustrated in Figs. **9**, **12**, **15**, **18**, **22** and **25**, the number of contact spots Figs. **11**, **14**, **17**, **20** and **21**, respectively, is accordingly increased for selective excitation of the given optical mode. Fig. **12** shows the optical field intensity distribution of the optical mode with lateral and longitudinal quantum numbers $n=1$ and $m=9$, respectively, in the triangle optical cavity. The axes **12-1** and **12-2** are X and Y coordinates for the triangle optical cavity, respectively. Z-axis **12-3** represents the optical field intensity that includes an optical field intensity maximum **12-5**. The dotted line **12-4** represents the border of the triangle optical cavity. Figs. **13** and **14** are two-dimensional diagrams that illustrate the shapes of contact spots in an upper electrode for selected cut-off levels in an embodiment of the light output device according to the invention corresponding to Fig. **12**. Fig. **13** shows the calculated shapes of the contact spots for the upper electrode for a given optical mode in the triangle optical cavity with lateral and longitudinal quantum numbers $n=1$ and $m=9$, respectively. Axes **13-1** and **13-2** are X and Y coordinates for the triangle optical cavity, respectively. The dotted line **13-3** represents the border of the triangle optical cavity. Contours **13-4**, **13-5** and **13-6** are the shapes of the contact spots for the upper electrode calculated at cut-off levels $L_c=0.1$, $L_c=0.5$ and $L_c=0.9$ corresponding to the maxima of optical field intensity in the triangle optical cavity. Fig. **14** shows

the shapes of the contact spots for the multi-contact upper electrode at the cut-off level L_c =0.5 for a given optical mode in the triangle optical cavity with lateral and longitudinal quantum numbers $n=1$ and $m=9$, respectively. Axes **14-1** and **14-2** are the X and Y coordinates for the triangle optical cavity, respectively. The dotted line **14-3** represents the border of the triangle optical cavity. Contour **14-4** represents the shape of a contact spot in the multi-contact upper electrode corresponding to an optical field intensity maximum in the triangle optical cavity at the cut-off level $L_c=0.5$.

Fig. **15** shows the optical field intensity distribution of the optical mode with lateral and longitudinal quantum numbers $n=1$ and $m=7$, respectively, in the triangle optical cavity. The axes **15-1** and **15-2** are X and Y coordinates for the triangle optical cavity, respectively. Z-axis **15-3** represents the optical field intensity that includes an optical field intensity maximum **15-5**. The dotted line **15-4** represents the border of the triangle optical cavity. Figs. **16** and **17** are two-dimensional diagrams that illustrate the shapes of contact spots in an upper electrode for selected cut-off levels in an embodiment of the light output device according to the invention corresponding to Fig. **15**. Fig. **16** shows the calculated shapes of the contact spots for the upper electrode for a given optical mode in the triangle optical cavity with lateral and longitudinal quantum numbers $n=1$ and $m=7$, respectively. Axes **16-1** and **16-2** are X and Y coordinates for the triangle optical cavity, respectively. The dotted line **16-3** represents the border of the triangle optical cavity. Contours **16-4**, **16-5** and **16-6** are the shapes of the contact spots for the upper electrode calculated at cut-off levels $L_c=0.1$, $L_c=0.5$ and $L_c=0.9$ corresponding to the maxima of optical field intensity in the triangle optical cavity. Fig. **17** shows the shapes of the contact spots for the multi-contact upper electrode at the cut-off level L_c =0.5 for a given optical mode in the triangle optical cavity with lateral and longitudinal quantum numbers $n=1$ and $m=7$, respectively. Axes **17-1** and **17-2** are the

X and Y coordinates for the triangle optical cavity, respectively. The dotted line **17-3** represents the border of the triangle optical cavity. Contour **17-4** represents the shape of a contact spot in the multi-contact upper electrode corresponding to an optical field intensity maximum in the triangle optical cavity at the cut-off level $L_c = 0.5$.

Fig. **18** shows the optical field intensity distribution of the optical mode with lateral and longitudinal quantum numbers $n = 1$ and $m = 11$, respectively, in the triangle optical cavity. The axes **18-1** and **18-2** are X and Y coordinates for the triangle optical cavity, respectively. Z-axis **18-3** represents the optical field intensity that includes an optical field intensity maximum **18-5**. The dotted line **18-4** represents the border of the triangle optical cavity. Figs. **19**, **20** and **21** are two-dimensional diagrams that illustrate the shapes of contact spots in an upper electrode for selected cut-off levels in an embodiment of the light output device according to the invention corresponding to Fig. **18**. Fig. **19** shows the calculated shapes of the contact spots for the upper electrode for a given optical mode in the triangle optical cavity with lateral and longitudinal quantum numbers $n = 1$ and $m = 11$, respectively. Axes **19-1** and **19-2** are X and Y coordinates for the triangle optical cavity, respectively. The dotted line **19-3** represents the border of the triangle optical cavity. Contours **19-4**, **19-5** and **19-6** are the shapes of the contact spots for the upper electrode calculated at cut-off levels $L_c = 0.1$, $L_c = 0.5$ and $L_c = 0.9$ corresponding to the maxima of optical field intensity in the triangle optical cavity. Fig. **20** shows the shapes of the contact spots for the multi-contact upper electrode at the cut-off level $L_c = 0.7$ for a given optical mode in the triangle optical cavity with lateral and longitudinal quantum numbers $n = 1$ and $m = 11$, respectively. Axes **20-1** and **20-2** are the X and Y coordinates for the triangle optical cavity, respectively. The dotted line **20-3** represents the border of the triangle optical cavity. Contour **20-4** represents the shape of a contact spot in the

multi-contact upper electrode corresponding to an optical field intensity maximum in the triangle optical cavity at the cut-off level $L_c=0.7$. Fig. **21** shows the shapes of the contact spots for the multi-contact upper electrode at the cut-off level $L_c=0.5$ for a given optical mode in the triangle optical cavity with lateral and longitudinal quantum numbers $n=1$ and $m=11$, respectively. Axes **21-1** and **21-2** are the X and Y coordinates for the triangle optical cavity, respectively. The dotted line **21-3** represents the border of the triangle optical cavity. Contour **21-4** represents the shape of a contact spot in the multi-contact upper electrode corresponding to an optical field intensity maximum in the triangle optical cavity at the cut-off level $L_c=0.5$.

For optical modes with large lateral and longitudinal quantum numbers, the number of contact spots also depends on the selected cut-off level L_c. For example, for optical modes with lateral quantum number $n=1$ and longitudinal quantum number $m=11$, whose optical field distribution is shown in Figs. **18** and **19**, the calculated number of contact spots on the upper electrode is three for $L_c=0.9$ for Fig. **19**, six for $L_c=0.7$ for Fig. **20**, and twelve for $L_c=0.5$ for Fig. **21**.

In addition, for a given optical mode with large lateral and longitudinal quantum numbers n and m, respectively, the resulting optical field intensity in the triangle optical cavity will generally include a large number of optical field intensity maxima. Therefore, it is desirable to associate one contact spot with a group of optical field intensity maxima. Thus, for large n and m the reduced number of contact spots $\tilde{N}_{spot}$ is

$$\tilde{N}_{spot} = N_{max}/N_{group} \qquad \text{Eq. (3)}$$

wherein N_{max} represents the maximum number of contact spots, $\tilde{N}_{spot}$ represents the reduced number of contact spots $\tilde{N}_{spot}$ and N_{group} represents the number of the optical field intensity maxima in the group corresponding to one contact spot. Equation (3) is generally valid for a

constant number of the optical field maxima in the group corresponding to one contact spot, i.e., N_{group} = *const*. For example, for a given optical mode with $n=2$ and $m=14$, whose optical field intensity distribution is shown in Figs. **22** and **23**, N_{max} $=12$ at $L_c=0.5$ to 0.9, and for N_{group} = 3, the reduced number of contact spots $\tilde{N}_{spot}$ = 4. Fig. **22** shows optical field intensity distribution for a given optical mode with lateral and longitudinal quantum numbers $n=2$ and $m=14$ in the triangle optical cavity, respectively. Axes **22-1** and **22-2** are X and Y coordinates for the triangle optical cavity respectively, Z-axis **22-3** represents the optical field intensity that includes an optical field intensity maximum **22-5.** The dotted line **22-4** is the border of the triangle optical cavity. Fig. **23** shows the calculated shapes of the contact spots for the upper electrode for a given optical mode in the triangle optical cavity with lateral and longitudinal quantum numbers $n=2$ and $m=14$. Axes **23-1** and **23-2** are X and Y coordinates for the triangle optical cavity, respectively. The dotted line **23-3** represents the border of the triangle optical cavity. Contours **23-4**, **23-5** and **23-6** are the shapes of the contact spots for the upper electrode calculated at cut-off levels $L_c=0.1$, $L_c=0.5$ and $L_c=0.9$, respectively. The corresponding shapes of the contact spots for the upper electrode is shown in Fig. **24**. Fig. **24** shows the shapes of the contact spots for the upper electrode with the reduced number of contact spots for a given optical mode in the triangle optical cavity with lateral and longitudinal quantum numbers $n=2$ and $m=14$. Axes **24-1** and **24-2** are X and Y coordinates for the triangle optical cavity, respectively, with a contact spot **24-4** out of the four contact spots ($\tilde{N}_{spot}$ = 4) for the upper electrode. The dotted line **24-3** represents the border of the triangle optical cavity. For a given optical mode with $n=3$ and $m=21$, whose optical field distribution is shown in Figs. **25** and **26**, $N_{max}=27$ at $L_c=0.5$ to 0.9 and for N_{group} = 3, the reduced number of contact spots $\tilde{N}_{spot}$ = 9. Fig. **25** shows the optical field intensity distribution for a given optical mode with

lateral and longitudinal quantum numbers $n=3$ and $m=21$ in the triangle optical cavity. Axes **25-1** and **25-2** are X and Y coordinates for the triangle optical cavity, respectively. Z-axis **25-3** represents the optical field intensity axis with an optical field intensity maximum **25-5**. The dotted line **25-4** represents the border of the triangle optical cavity. Fig. **26** shows the calculated shapes of the contact spots for the upper electrode for a given optical mode in the triangle optical cavity with lateral and longitudinal quantum numbers $n=3$ and $m=21$. Axes **26-1** and **26-2** are X and Y coordinates for the triangle optical cavity, respectively. The dotted line **26-3** represents the border of the triangle optical cavity. Contours **26-4**, **26-5** and **26-6** are the shapes of the contact spots for the upper electrode calculated at cut-off levels $L_c=0.1$, $L_c=0.5$ and $L_c=0.9$, respectively. The corresponding shapes of the contact spots for the upper electrode is shown in Fig. **27**. Fig. **27** shows shape of multiple upper TDI electrode with the reduced number of contact for mode in triangle optical cavity with quantum numbers n $=3$ and m $=21$. Axes **27-1** and **27-2** are X and Y coordinates for the triangle optical cavity, respectively, with a contact spot **27-4** out of the nine contact spots ($\tilde{N}_{spot}$ = 9) for the upper electrode. The dotted line **27-3** represents the border of the triangle optical cavity.

Note that Equation (3) is generally valid for a constant number of the optical field maxima in the group corresponding to one contact spot, i.e., N_{group} = *const.*

According to yet another embodiment of the invention, a variable number for the optical field intensity maxima is used for the group of contact spots corresponding to one contact spot $N_{group}(i)$, where i represents the index numerating the contact spots. Thus, Equation (3) is accordingly modified as follows:

$$N_{\max} = \sum_{i=1}^{\tilde{N}_{spot}} N_{group}(i) \qquad \text{Eq. (4)}$$

For example, for a given optical mode with lateral and longitudinal quantum numbers $n=1$ and $m=21$, respectively, whose optical field intensity distribution is shown in Figs. **28** and **29**, N_{max} =34 at the cut-off level L_c=0.5 for Fig. **30**. For $N_{group}(i)$ = 3, with i=1,2,3, $N_{group}(i)$ = 5, with i=4,5,6, and $N_{group}(i)$ = 10, with i=7, according to Equation (4) N_{max} = $3\times3+3\times5+1\times10$ = 34. Fig. **28** shows intensity distribution of the optical mode with lateral and longitudinal quantum numbers $n=1$ and $m=21$ in the triangle optical cavity, respectively. Axes **28-1** and **28-2** are X and Y coordinates for the triangle optical cavity, respectively. Z-axis **28-3** represents the optical field intensity with an optical field intensity maximum **28-5**. The dotted line **28-4** represents the border of the triangle optical cavity. Fig. **29** shows the calculated shapes of the contact spots for the upper electrode for a given optical mode in the triangle optical cavity with lateral and longitudinal quantum numbers $n=3$ and $m=21$, respectively. Axes **29-1** and **29-2** are X and Y coordinates for the triangle optical cavity, respectively. The dotted line **29-3** represents the border of the triangle optical cavity. Contours **29-4** and **29-5** are the shapes of the contact spots for the upper electrode calculated at the cut-off levels L_c=0.1 and L_c=0.5, respectively. Fig. **30** shows the shapes of the contact spots for the upper electrode at the cut-off level L_c=0.5 for a given optical mode in the triangle optical cavity with lateral and longitudinal quantum numbers $n=1$ and $m=21$, respectively. Axes **30-1** and **30-2** are X and Y coordinates for the triangle optical cavity, respectively, having a plurality of contact spots for the upper electrode including the contact spot **30-4**. The dotted line **30-3** represents the border of the triangle optical cavity. The corresponding shapes of the contact spots for the upper electrode is shown in Fig. **31**. Fig. **31** shows the shapes of the contact spots for the upper electrode with a reduced number of contact spots for a given optical mode in the triangle optical cavity with lateral and longitudinal quantum numbers $n=1$ and

$m=21$, respectively. Axes **31-1** and **31-2** are X and Y coordinates for the triangle optical cavity, respectively, having a plurality of contact spots for the upper electrode including the contact spot **31-4**. The dotted line **31-3** represents the border of the triangle optical cavity.

In a limited case where $N_{group} = N_{max}$ the upper electrode can have a single contact spot as shown in Fig. **32** for a given optical mode with $n=1$ and $m=21$. Fig. **32** shows the shape of a single contact spot of the upper electrode with a reduced number of contact for mode in triangle optical cavity with quantum numbers $n=1$ and $m=21$, respectively. Axes **32-1** and **32-2** are X and Y coordinates for the triangle optical cavity, respectively, having a single contact spot **32-4** for the upper electrode. The dotted line **32-3** represents the border of the triangle optical cavity. The optical mode selectivity for the upper electrode with a reduced number of contact spots where $N_{group}>1$ is lower than that of the upper electrode where $N_{group}=1$. However, in combination with the optical mode selectivity related to gain spectrum and quality factor, an upper electrode with a reduced number of contact spots can be applied to single-optical-mode semiconductor laser fabrication.

For additional selection of the non-uniformly spatially distributed optical modes in the triangle optical cavity, the parts of the triangle cavity with minimal optical field intensity can be cut out or disregarded. For example, for selective light or laser generation of a given optical mode with $n=1$ and $m=5$ as shown in Fig. **9**, the edges of the triangle optical cavity can be cut out along the dotted line **96** of Fig. **9** and, similarly, the dotted line **10-7** of Fig. **10**. A truncated triangle optical cavity is thus formed, as shown in Fig. **2**.

One of the many advantages of the light output device according to the invention (e.g., a semiconductor laser diode) is that its triangle optical cavity includes an optimal quality factor of longitudinal optical

modes, resulting from the total internal reflection at all triangular facets as long as the refractive index of the semiconductor is greater than 2.0. Furthermore, the light output device according to the invention can operate in a single optical mode or controllable multi-mode regimes such as applications in compact disk (CD) and digital video disk (DVD) pick-up heads, laser printers, and communications devices. In addition, the shape of the semiconductor laser diode makes it technologically simple for assembly into arrays or matrixes for lower power thresholds and increased output power. Optical connection between adjacent mesa structures in an array or matrix can be controlled by the width, depth and shape of the trenches providing optical communication between the mesa structures as shown in and described herein and above in conjunction with Figs. **3**, **4** and **5**. The direction of light output from the array or matrix of mesa structures in the light output device according to the invention is controlled by the shape of the light output element as shown in and described herein and above in conjunction with Figs. **3** and **4**. Moreover, the mesa structures in the light output device according to the invention can be made of a specially designed triangle different from those in the array, or a waveguide ridge, an optical fiber and other waveguide structures. Several arrays with different sizes of triangle optical cavities or different shapes of upper electrodes can be used for fabricating multi-wavelength light output devices such as a semiconductor laser diode needed for communications applications. A further advantage of the light output device according to the invention is the triangle shape of the mesa structures that makes it technologically simple to fabricate two-dimensional triangle lattice on the semiconductor wafer. This allows a total and optimal utilization of the semiconductor wafer for the production of semiconductor laser matrixes and arrays of various shapes. The semiconductor laser output devices having triangle optical cavities with spatially distributed current injection according to the invention includes

hollow matrixes with various topologies, including hollow triangle, hollow hexagon and other topologies that can be used for laser gyroscope applications as shown in and described herein and above in conjunction with Fig. **5**.

Fig. **33** is a diagram that illustrates a further embodiment of the light output device having a triangle optical cavity according to the invention. The light output device with spatially distributed current injection as shown in Fig. **33**, e.g., a semiconductor laser diode, operates with the light output by the light output device being generated with wavelength λ in the general region of 700 nm to 1000 nm. According to this particular embodiment of the invention, the light output device includes a lower electrode **33-1**, a conducting n-GaAs substrate **33-2**, a triangle mesa structure **33-3** having a triangle optical cavity, and an upper multi-contact electrode **33-8** having a plurality of contact spots formed thereon. The contact spots correspond to the maxima of optical field intensity for at lease one optical mode on a lateral plane in the triangle optical cavity, which are shaped as discussed herein and above, e.g., in conjunction with Fig. **8**, Fig. **11**, Fig. **14**, Fig. **17**, Fig. **20**, Fig. **21**, Fig. **24**, Fig. **27**, Fig. **30**, Fig. **31** or Fig. **32**. In this particular embodiment, the triangle mesa structure **33-3** further comprises a high-index AlGaAs two-dimensional waveguide layer **33-4**, a lower waveguide mirror **33-5** made of a low-index n-type AlGaAs cladding layer or n-type AlGaAs superlattice, an upper waveguide mirror **33-6** made of a low-index p-type AlGaAs cladding layer or p-type AlGaAs superlattice, and an upper contact layer **33-7** made of p-type AlGaAs. The contact spots in the upper electrode **33-8** are shaped by a non-uniform metal deposition, a metal deposition over a dielectric mask with windows or openings, a non-uniform doping of the upper contact layer **33-7**, or an ion-implantation treatment of the upper contact layer **33-7**. Further to this particular embodiment, the waveguide layer **33-4** includes an active layer **33-9** made of InGaAs/GaAlAs double

heterostructure, InGaAs/GaAlAs single quantum well, InGaAs/GaAlAs multiple quantum wells, or a current asymmetric resonance tunnelling structure. Moreover, the triangle mesa structure **33-3** can also be a truncated triangle mesa structure, and the triangle optical cavity can be truncated as well, as discussed herein and above.

In a variation of the embodiment according the invention as shown in Fig. **33**, the light output device with spatially distributed current injection, e.g., a semiconductor laser diode, operates with the light output by the light output device being generated with wavelength λ in the general region of 1300 nm. This varied embodiment is similar in structure to the one shown in Fig. **33**, except that the active layer **33-9** in the waveguide layer **33-4** is made of GaAsSb/GaAlAs double heterostructure, InGaAsN/GaAlAs double heterostructure, GaAsSb/GaAlAs single quantum well, InGaAsN/GaAlAs single quantum well, GaAsSb/GaAlAs multiple quantum wells, InGaAsN/GaAlAs multiple quantum wells, or a current asymmetric resonance tunnelling structure.

In a further variation of the embodiment according the invention as shown in Fig. **33**, the substrate **33-2** can be a conducting n-InP substrate with the light output by the light output device being generated with wavelength λ in the general region of 1300 nm to 1550 nm. According to this varied embodiment of the invention, the triangle mesa structure **33-3** comprises a high-index InGaAsP two-dimensional waveguide layer **33-4**, a lower waveguide mirror **33-5** made of an n-type InP cladding layer, n-type InGaAsP/InGaAsP superlattice or n-type AlInGaAs/AlInGaAs superlattice, an upper waveguide mirror **33-6** made of an p-type InP cladding layer or p-type InGaAsP superlattice, and an upper contact layer **33-7** made of p-type InP. The waveguide layer **33-4** further includes an active layer **33-9** made of InGaAsP/InGaAsP double heterostructure, InGaAsP/InGaAsP single quantum well, InGaAsP/InGaAsP multiple quantum wells, or a current asymmetric

resonance tunnelling structure. Similarly, the triangle mesa structure **33-3** can also be a truncated triangle mesa structure, and the triangle optical cavity can be truncated as well, as discussed herein and above.

Fig. **34** is a diagram that illustrates another embodiment of the light output device having a triangle optical cavity according to the invention. The light output device with spatially distributed current injection as shown in Fig. **34**, e.g., a semiconductor laser diode, operates with the light output by the light output device being generated with wavelength λ in the general region of 400 nm to 700 nm. According to this particular embodiment of the invention, the light output device includes a lower electrode **34-1** with a conducting n-GaN layer **34-2** formed on a sapphire substrate **34-3** with a buffer layer **34-11** made of BAlGaInN, a triangle mesa structure **34-4** having a triangle optical cavity, and an upper multi-contact electrode **34-9** having a plurality of contact spots formed thereon. The contact spots correspond to the maxima of optical field intensity for at lease one optical mode on a lateral plane in the triangle optical cavity, which are shaped as discussed herein and above, e.g., in conjunction with Fig. **8**, Fig. **11**, Fig. **14**, Fig. **17**, Fig. **20**, Fig. **21**, Fig. **24**, Fig. **27**, Fig. **30**, Fig. **31** or Fig. **32**. In this particular embodiment, the triangle mesa structure **34-4** further comprises a high-index InGaN two-dimensional waveguide layer **34-5**, a lower waveguide mirror **34-6** made of a low-index n-type AlGaN cladding layer or n-type AlGaN superlattice, an upper waveguide mirror **34-7** made of a low-index p-type AlGaN cladding layer or p-type AlGaN superlattice, and an upper contact layer **34-8** made of p-type AlGaN. The contact spots in the upper electrode **34-9** are shaped by a non-uniform metal deposition, a metal deposition over a dielectric mask with windows or openings, a non-uniform doping of the upper contact layer **34-8**, or an ion-implantation treatment of the upper contact layer **34-8**. Further to this particular embodiment, the waveguide layer **34-5** includes an active layer **34-10** made of InGaN/InGaAlN double

heterostructure, InGaN/InGaAlN single quantum well, InGaN/InGaAlN multiple quantum wells, or a current asymmetric resonance tunnelling structure. Moreover, the triangle mesa structure can also be a truncated triangle mesa structure, and the triangle optical cavity can be truncated as well, as discussed herein and above.

Fig. **35** is a diagram that illustrates yet another embodiment of the light output device having a triangle optical cavity according to the invention. The light output device with spatially distributed current injection as shown in Fig. **35**, e.g., a semiconductor laser diode, operates with the light output by the light output device being generated with wavelength λ in the general region of 400 nm to 700 nm. According to this particular embodiment of the invention, the light output device includes a lower electrode **35-1** with a conducting n-SiC substrate **35-2**, a buffer layer **35-3** made of BAlGaInN, an n-GaN layer **35-4**, a triangle mesa structure **35-5** having a triangle optical cavity, and an upper multi-contact electrode **33-10** having a plurality of contact spots formed thereon. The contact spots correspond to the maxima of optical field intensity for at lease one optical mode on a lateral plane in the triangle optical cavity, which are shaped as discussed herein and above, e.g., in conjunction with Fig. **8**, Fig. **11**, Fig. **14**, Fig. **17**, Fig. **20**, Fig. **21**, Fig. **24**, Fig. **27**, Fig. **30**, Fig. **31** or Fig. **32**. In this particular embodiment, the triangle mesa structure **35-5** further comprises a high-index InGaN two-dimensional waveguide layer **35-6**, a lower waveguide mirror **35-7** made of a low-index n-type AlGaN cladding layer or n-type AlGaN superlattice, an upper waveguide mirror **35-8** made of a low-index p-type AlGaN cladding layer or p-type AlGaN superlattice, and an upper contact layer **35-9** made of p-type AlGaN. The contact spots in the upper electrode **35-10** are shaped by a non-uniform metal deposition, a metal deposition over a dielectric mask with windows or openings, a non-uniform doping of the upper contact layer **35-9**, or an ion-implantation treatment of

the upper contact layer **35-9**. Further to this particular embodiment, the waveguide layer **35-6** includes an active layer **35-11** made of InGaN/InGaAlN double heterostructure, InGaN/InGaAlN single quantum well, InGaN/InGaAlN multiple quantum wells, or a current asymmetric resonance tunnelling structure. Moreover, the triangle mesa structure can also be a truncated triangle mesa structure, and the triangle optical cavity can be truncated as well, as discussed herein and above.

Fig. **36** is a diagram that illustrates an additional embodiment of the light output device having a triangle optical cavity according to the invention. The light output device with spatially distributed current injection as shown in Fig. **36**, e.g., a cascade semiconductor laser diode, operates with the light output by the light output device being generated with wavelength λ in the general region of 5000 nm to 12000 nm. According to this particular embodiment of the invention, the light output device includes a lower electrode **36-1**, a conducting n-GaAs substrate **36-2**, a triangle mesa structure **36-3** having a triangle optical cavity, and an upper multi-contact electrode **36-8** having a plurality of contact spots formed thereon. The contact spots correspond to the maxima of optical field intensity for at lease one optical mode on a lateral plane in the triangle optical cavity, which are shaped as discussed herein and above, e.g., in conjunction with Fig. **8**, Fig. **11**, Fig. **14**, Fig. **17**, Fig. **20**, Fig. **21**, Fig. **24**, Fig. **27**, Fig. **30**, Fig. **31** or Fig. **32**. In this particular embodiment, the triangle mesa structure **36-3** further comprises a high-index two-dimensional waveguide layer **36-4** made of InGaAs quantum cascade superlattice, a lower waveguide mirror **36-5** made of a low-index n-type AlGaAs cladding layer or n-type AlGaAs superlattice, an upper waveguide mirror **36-6** made of a low-index p-type AlGaAs cladding layer or p-type AlGaAs superlattice, and an upper contact layer **36-7** made of p-type AlGaAs. The contact spots in the upper electrode **36-8** are shaped by a non-uniform metal deposition, a metal deposition over

a dielectric mask with windows or openings, a non-uniform doping of the upper contact layer **36-7**, or an ion-implantation treatment of the upper contact layer **36-7**. The triangle mesa structure **36-3** can also be a truncated triangle mesa structure, and the triangle optical cavity can be truncated as well, as discussed herein and above.

Fig. **37** is a diagram that illustrates yet an additional embodiment of the light output device having a triangle optical cavity according to the invention. The light output device with spatially distributed current injection as shown in Fig. **37**, e.g., a semiconductor laser diode, operates with the light output by the light output device being generated with wavelength λ in the general region of 400 nm to 700 nm. According to this particular embodiment of the invention, the light output device includes a lower electrode **37-1** with a conducting n-GaN layer **37-2** formed on a sapphire substrate **37-3** with a buffer layer **37-9** made of BAlGaInN, a plurality of triangle mesa structures (including mesa structure **37-4**) in an array along with a plurality of triangle optical cavities, upper multi-contact electrodes (including the upper electrode **37-5**) having a plurality of contact spots formed thereon, a plurality of trenches **37-6** providing optical connection between adjacent mesa structures, and a light output structure **37-7** for outputting light in the direction **37-8**. The contact spots correspond to the maxima of optical field intensity for at lease one optical mode on a lateral plane in each of the triangle optical cavities, which are shaped as discussed herein and above, e.g., in conjunction with Fig. **8**, Fig. **11**, Fig. **14**, Fig. **17**, Fig. **20**, Fig. **21**, Fig. **24**, Fig. **27**, Fig. **30**, Fig. **31** or Fig. **32**. In this particular embodiment, the triangle mesa structures of the light output device according to the invention are generally the same in structure to the triangle mesa structure **34-4** of Fig. **34**, which comprises a high-index InGaN two-dimensional waveguide layer, a lower waveguide mirror made of a low-index n-type AlGaN cladding layer or n-type AlGaN superlattice, an upper

waveguide mirror made of a low-index p-type AlGaN cladding layer or p-type AlGaN superlattice, and an upper contact layer made of p-type AlGaN. The contact spots in the upper electrodes are shaped by a non-uniform metal deposition, a metal deposition over a dielectric mask with windows or openings, a non-uniform doping of the upper contact layer, or an ion-implantation treatment of the upper contact layer. Further to this particular embodiment, the waveguide layer includes an active layer made of InGaN/GaAlN double heterostructure, InGaN/GaAlN single quantum well, InGaN/InGaAlN multiple quantum wells, or a current asymmetric resonance tunnelling structure. Moreover, the triangle mesa structures can also be truncated triangle mesa structures, and the triangle optical cavities can be truncated as well, as discussed herein and above.

Fig. **38** is a diagram that illustrates yet another embodiment of the light output device having a triangle optical cavity according to the invention. The light output device with spatially distributed current injection as shown in Fig. **38**, e.g., a semiconductor laser diode, operates with the light output by the light output device being generated with wavelength λ in the general region of 400 nm to 700 nm. According to this particular embodiment of the invention, the light output device includes a lower electrode **38-1** with a conducting n-SiC substrate **38-2**, a buffer layer **38-9** made of BAlGaInN, a n-GaN layer **38-3**, a plurality of triangle mesa structures (including triangle mesa structure **38-4**) in an array along with a plurality of triangle optical cavities, upper multi-contact electrodes (including the upper electrode **38-5**) having a plurality of contact spots formed thereon, a plurality of trenches **38-6** providing optical connection between adjacent mesa structures, and a light output structure **38-7** for outputting light in the direction **38-8**. The contact spots correspond to the maxima of optical field intensity for at lease one optical mode on a lateral plane in each of the triangle optical cavities, which are shaped as discussed herein and above,

e.g., in conjunction with Fig. **8**, Fig. **11**, Fig. **14**, Fig. **17**, Fig. **20**, Fig. **21**, Fig. **24**, Fig. **27**, Fig. **30**, Fig. **31** or Fig. **32**. In this particular embodiment, the triangle mesa structures of the light output device according to the invention are generally the same in structure to the triangle mesa structure **35-5** of Fig. **35**, which comprises a high-index InGaN two-dimensional waveguide layer, a lower waveguide mirror made of a low-index n-type AlGaN cladding layer or n-type AlGaN superlattice, an upper waveguide mirror made of a low-index p-type AlGaN cladding layer or p-type AlGaN superlattice, and an upper contact layer made of p-type AlGaN. The contact spots in the upper electrodes are shaped by a non-uniform metal deposition, a metal deposition over a dielectric mask with windows or openings, a non-uniform doping of the upper contact layer, or an ion-implantation treatment of the upper contact layer. Further to this particular embodiment, the waveguide layer includes an active layer made of InGaN/InGaAlN double heterostructure, InGaN/InGaAlN single quantum well, InGaN/InGaAlN multiple quantum wells, or a current asymmetric resonance tunnelling structure. Moreover, the triangle mesa structures can also be truncated triangle mesa structures, and the triangle optical cavities can be truncated as well, as discussed herein and above.

Fig. **39** is a diagram that illustrates yet another embodiment of the light output device having a triangle optical cavity according to the invention. The light output device with spatially distributed current injection as shown in Fig. **39**, e.g., a semiconductor laser diode, operates with the light output by the light output device being generated with wavelength λ in the general region of 400 nm to 700 nm. According to this particular embodiment of the invention, the light output device includes a lower electrode **39-1** with a conducting n-SiC substrate **39-8** with a buffer layer **39-9** made of BAlGaInN, a n-GaN layer **39-2**, a plurality of triangle mesa structures (including triangle mesa structure **39-4**) in a matrix along with a

plurality of triangle optical cavities, upper multi-contact electrodes (including the upper electrode **39-4**) having a plurality of contact spots formed thereon, a plurality of trenches **39-5** providing optical connection between adjacent mesa structures, and a light output structure **39-6** for outputting light in the direction **39-7**. The contact spots correspond to the maxima of optical field intensity for at lease one optical mode on a lateral plane in each of the triangle optical cavities, which are shaped as discussed herein and above, e.g., in conjunction with Fig. **8**, Fig. **11**, Fig. **14**, Fig. **17**, Fig. **20**, Fig. **21**, Fig. **24**, Fig. **27**, Fig. **30**, Fig. **31** or Fig. **32**. In this particular embodiment, the triangle mesa structures of the light output device according to the invention are generally the same in structure to the triangle mesa structure **34-4** of Fig. **34**, which comprises a high-index InGaN two-dimensional waveguide layer, a lower waveguide mirror made of a low-index n-type AlGaN cladding layer or n-type AlGaN superlattice, an upper waveguide mirror made of a low-index p-type AlGaN cladding layer or p-type AlGaN superlattice, and an upper contact layer made of p-type AlGaN. The contact spots in the upper electrodes are shaped by a non-uniform metal deposition, a metal deposition over a dielectric mask with windows or openings, a non-uniform doping of the upper contact layer, or an ion-implantation treatment of the upper contact layer. Further to this particular embodiment, the waveguide layer includes an active layer made of InGaN/GaAlN double heterostructure, InGaN/GaAlN single quantum well, InGaN/InGaAlN multiple quantum wells, or a current asymmetric resonance tunnelling structure. Moreover, the triangle mesa structures can also be truncated triangle mesa structures, and the triangle optical cavities can be truncated as well, as discussed herein and above.

Although the invention has been particularly shown and described in detail with reference to the preferred embodiments thereof, the embodiments are not intended to be exhaustive or to limit the invention to

the precise forms disclosed herein. It will be understood by those skilled in the art that many modifications in form and detail may be made without departing from the spirit and scope of the invention. Similarly, any process steps described herein may be interchangeable with other steps to achieve substantially the same result. All such modifications are intended to be encompassed within the scope of the invention, which is defined by the following claims and their equivalents.